USDA

Hubbard Brook Experimental Forest

Amey S. Bailey

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Amey S. Bailey has been a forestry technician with the Northeastern Forest Experiment Station at the Hubbard Brook Experimental Forest since 1992. She has a B.A. in botany from Connecticut College and an M.F. from Duke University.

Cover Photo

Aerial view of the Hubbard Brook Experimental Forest showing Watershed 4 on left (36 ha) which was strip cut in 1970, 1972, and 1974; and Watershed 2 (16 ha) experimentally clearfelled in 1965 and treated with herbicides.

HUBBARD BROOK EXPERIMENTAL FOREST

INTRODUCTION

The Hubbard Brook Experimental Forest (HBEF) is a 3,160 ha reserve dedicated to long-term study of forest and stream ecosystems. Located in the White Mountain National Forest of New Hampshire, HBEF was established in 1955 and is operated by the USDA Forest Service's Northeastern Forest Experiment Station. In 1963, the U.S. Forest Service with scientists from Dartmouth College, developed the Hubbard Brook Ecosystem Study to expand watershed level hydrologic studies to include water quality research. Later, Yale and Cornell Universities, and the Institute of Ecosystem Studies joined the consortium.

This cooperative effort now includes many educational institutions, government agencies, and foundations that continue to produce extensive information on the biology, geology, chemistry and human disturbance of forest and freshwater ecosystems. Commitment to this type of long-term ecological research provides quality baseline data that are used to detect trends through space and time, while providing guidelines for ecosystem management. The Hubbard Brook database is a rare and valuable resource to be called upon during these times of rapid environmental change.

CHARACTERISTICS OF HBEF

History

In 1783, William Hobart established the first farm in Hubbard Brook valley between Hubbard Brook and Mirror Lake. The brook takes its name from a common variant of William Hobart's surname. Subsistence farming dominated the settlement years followed by a time of small industry sustained by lumber and farming which grew into the logging era by the late 1800s. By 1920, 200 million board feet of spruce and some hardwoods had been logged from the valley. At this time, 91 percent of the total merchantable timber in the valley had been cut.

The Weeks Act of 1911 allowed the federal government to buy private land holdings to protect the watersheds of navigable rivers, enabling establishment of the eastern National Forests. In 1920, the United States Government bought the land in upper Hubbard Brook Valley for $7.71/acre as part of an effort by conservation organizations to establish the White Mountain Forest Preserve. During the early years of federal ownership, Hubbard Brook existed as a wildlife management area where

public access was encouraged, but hunting was restricted by the state.

The present structure of Hubbard Brook forest was shaped not only by logging but also by the hurricane of 1938. The hurricane swept across the valley from the Southeast blowing down trees, exposing mineral soil and opening up tracts of land. As a result of these events, much of the forest today is approximately 80 years old with patches of younger trees, and many that are much older.

In 1955, the entire 3,160 ha valley was set aside as a permanent site for watershed management research. Some of the features that make Hubbard Brook a desirable location for this research are: uniform topography, soil types, forest cover, relatively water tight bedrock, numerous small watersheds, and the capacity for soil water to completely recharge during the dormant season.

Site Characteristics

HBEF is located at 43°56'N latitude and 71°45'W longitude. The bowl-shaped drainage basin of Hubbard Brook ranges in elevation from 222 m where Hubbard Brook leaves the valley to 1,015 m at the top of Mount Kineo. Although HBEF is only 116 km from the Atlantic Ocean, the climate is humid-continental with short, cool summers and long, cold winters. The average monthly temperature is 19° C in July and -9° C in January. The average number of days without killing frost is 100 and the growing season for trees extends from the end of May (time of full leaf development) to mid-October (leaf fall). Average solar radiation is about 11.1×10^9 kcal/ha/yr. Of the solar radiation received by the Hubbard Brook valley during the growing season, 15 percent is reflected, 41 percent is lost as heat, 42 percent is used in transpiration and evaporation of water, and 2 percent supports the biological functions of the ecosystem. Average minimum daily relative humidity is about 60 percent. Winds from the Northwest are most common, though southerly winds occur fairly frequently but are usually light.

Facilities

The Robert S. Pierce Ecosystem Laboratory provides office space, laboratories, conference facilities, living quarters, a shop, a garage and storage space in West Thornton, New Hampshire. Additional offices and laboratories are located in Durham, New Hampshire at the Forestry Sciences Laboratory. The White Mountain National Forest maintains 16 km of gravel roads on the Experimental Forest and a trail system provides

access to outlying research sites. An archive building provides long-term storage for research samples.

Description of Watersheds

In 1955, researchers began installing stream gaging stations and precipitation collectors to study water movement through forests. By 1967, eight stream gaging stations had been constructed. A ninth was completed in 1994. Six of the gaged watersheds are located on the south-facing slope of the Hubbard Brook valley and three are on the north-facing slope. Precipitation collectors are sampled weekly at 24 locations throughout the gaged watersheds. At the bottom of each watershed, the stream flows into a concrete stilling basin and over a V-notch weir, or through a metal flume and a V-notch combination. Calibrated stage-height recorders measure streamflow continuously throughout the year (fig. 1).

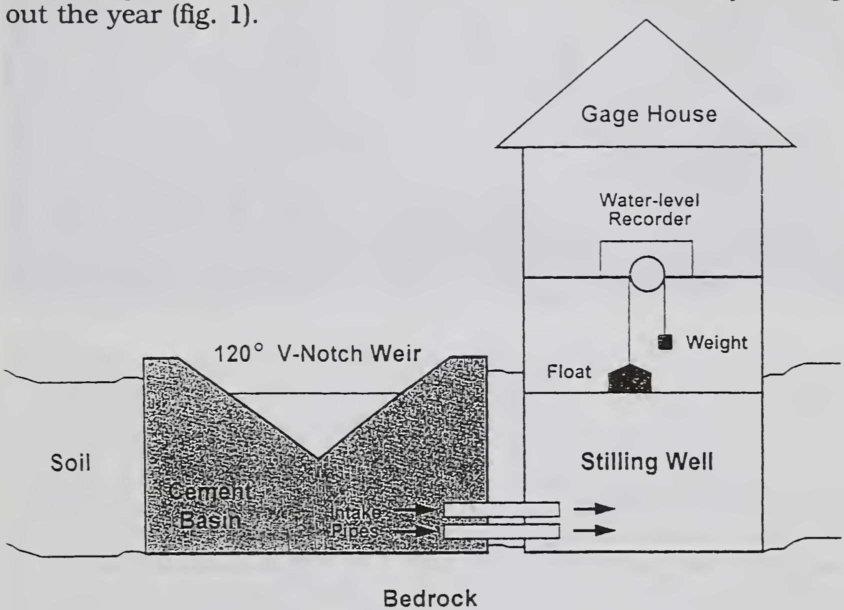


Figure 1.--Stream gaging station with 120° V-notch.

The small watershed approach to nutrient cycling in ecosystems was pioneered at Hubbard Brook. The technique designates a watershed as the basic unit for ecosystem study to determine inputs, outputs and internal cycling of water, nutrients, and energy. Small watersheds (ranging from 12 to 76 hectares) at HBEF have well-defined boundaries where the topographic divide coincides closely with the water divide.

Small watersheds are used in studies of nutrient cycling because of the close link between the movement of water and

Gaging station for year-round monitoring of streamflow.

nutrients. Precipitation and dry deposition are major sources of sulfur and nitrogen. Weathering of bedrock and soil supplies dissolved calcium, potassium and magnesium. These and other elements are cycled within the forest ecosystem. Losses occur in streamflow, as gases, or in windblown materials. It is these reservoirs and fluxes of nutrients that Hubbard Brook scientists measure. Often the scientific goal is to establish nutrient budgets that quantify the amount of a certain element stored or moving through the ecosystem. Nutrient cycles provide a valuable tool for assessing forest health and aspects of disturbances such as acid rain and forest harvests.

Hydrology

The Hubbard Brook Experimental Forest contains numerous headwater streams. Stream temperatures range from near 0° C in the winter to about 18° C in the summer. These headwater streams are generally acidic (pH 4.9) and high in dissolved oxygen, but low in organic carbon and nutrients. Streamflow in the headwater streams ranges from near zero during summer droughts to hundreds of cubic meters per hectare per day during storms or snowmelt. Sediment carried by 3 undisturbed watersheds averages 23 to 54 kg/ha/yr, but

ranges from 1 to 141. The magnitude of sediment transport is regulated by individual storm events.

The water budget at the HBEF is based on long-term measurements of precipitation and streamflow. Precipitation enters the ecosystem and after short periods of storage in the soil or snowpack, leaves as streamflow or evapotranspiration (water evaporated directly from leaves, soil and snow). Approximately 1 percent of the total annual precipitation leaves the watershed through seepage to bedrock. At Hubbard Brook, the average annual hydrologic budget is: Precipitation (132 cm) = Streamflow (81 cm) + Evaporation (51 cm). Or, 61 percent of the precipitation that enters the ecosystem leaves as streamflow, while 39 percent is returned to the atmosphere by evapotranspiration.

Average annual precipitation is 132 cm with a winter snowpack of about 1.5 m. On average, approximately 11 cm of precipitation falls monthly. However, streamflow is not evenly distributed. Thirty percent of total annual streamflow is recorded in April and May during snowmelt. Streams are lowest in the summer when the trees are readily transpiring. In the winter, streams freeze over and become snow covered, but baseflow serves as a source of water throughout the winter (fig. 2). The occurrence of soil frost varies from year to year, according to the timing of snowpack development and the arrival of extremely cold weather.

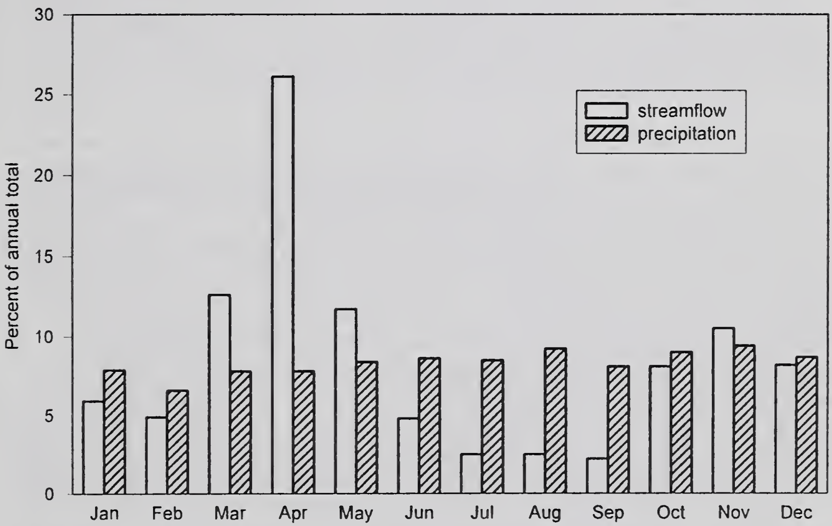


Figure 2.--Percent of annual total precipitation and streamflow for Watershed 3 (1958-1996).

Geology

The bedrock of the Hubbard Brook valley consists of granitic rocks of the Kinsman Quartz Monzonite in the western portion of the valley and highly metamorphosed sedimentary rocks of the Rangeley Formation in the eastern portion. Quartzites, mica schists, and calc-silicates occur in varying portions within the formation. Intrusions of granite pegmatite, two-mica (Concord) granite, and mafic dikes ranging from basalt to camptonite are common within the country rock. In some portions of the valley, one lithology dominates, whereas in other portions lithology may change as much as once per meter across the bedrock surface. Bedrock is exposed on only a few percent of the valley's area, principally in stream channels and along ridges.

The bedrock surface was scraped clean of existing soils and surficial deposits during the last advance of Wisconsinian glaciation. Subsequent deposition in the Hubbard Brook valley included till, an unsorted mixture of boulders, cobbles, gravel, sand, silt, and clay which accumulated at the ice/bedrock interface or dropped out of the ice as it melted. Stratified deposits of sand and gravel were left in some lower parts of the valley where sediments were reworked and sorted by meltwater as the glacier receded.

Soils

Hubbard Brook soils are primarily spodosols developed in acidic glacial till with loamy sand to sandy loam textures. Depth to bedrock ranges from 0-3 meters. Due to high porosity, little overland flow of water or surface erosion occurs. Surface topography is rough with pits and mounds caused by uprooting of fallen trees and numerous boulders.

A typical soil series in the HBEF is the Becket series, a well-drained loamy sand with the following general characteristics: an organic layer (4 cm thick) of fresh (Oi horizon) and decomposing (Oe horizon) plant litter at the surface; a 5 to 7 cm thick layer of well decomposed organic matter (Oa), pH 3.5; a leached, light gray, fine sandy layer about 7 cm thick (E), pH 4.0; the subsoil, extending to a depth of about 65 cm, which is a dark, reddish-brown, fine sandy loam in the zone (upper 15 cm) of organic matter, iron, aluminum accumulation (Bh and Bs1), pH 4.5; a brownish-yellow, fine sandy loam in the next 23 cm (Bs2) pH 4.7; and a light olive-brown, fine sandy loam in the lower 15 cm (Bs3) pH 5.0. Below the Bs3 to a depth of 100 cm or more is a compact layer of very firm, grayish-brown, gravelly loamy sand (C), pH 5.2.

Soil temperature varies seasonally and with depth. In the winter, soil temperatures increase with depth but decline gradually throughout the cold months. At 90 cm depth soil tempera-

ture is about 4.5° C on January 1 and 3° C on April 1. After snowmelt, warming near the surface is rapid because the sun is high and leaves are not yet developed. Maximum temperatures occur in July and August reaching an average of 17° C at 2.5 cm. Canopy closure prevents further warming and the surface soil remains approximately the same as air temperature under the canopy. The soil is isothermal (the same temperature at all depths) in April and September.

Vegetation

The forest at Hubbard Brook is dominated by unevenaged, second growth, northern hardwoods. Forest vegetation varies with slope, aspect, soil depth, and other environmental characteristics. Prior to the 1900s, approximately 50 percent of the basal area was red spruce. Today, red spruce can be found only on ridge tops and rocky outcrops. Sugar maple, yellow birch, and beech (collectively known as the northern hardwoods) regenerated after logging and now comprise over 90 percent of the basal area. North-facing slopes have a higher proportion of conifers. Hobblebush and striped maple are common understory plants and Canada mayflower, trout lily, raspberry, hardwood seedlings, and ferns typify the herbaceous forest floor.

The forest has an average of 567 stems/ha with a basal area of 26 m^2/ha and biomass consisting of 237 metric tons/ha for trees greater than or equal to 10 cm diameter at breast height (d.b.h.). The mature forest is comprised of shade tolerant species that started in the understory and upon release by logging or other disturbance assumed a dominant position. Upon removal of the overstory, pin cherry germinates and becomes a dominant successional species for about 30 years, at which point it is replaced by the more tolerant northern hardwood species.

THE RESEARCH PROGRAM

HUBBARD BROOK ECOSYSTEM STUDY (HBES)

Until the early 1960s, research on physical aspects of forest hydrology such as water yield, erosion and sedimentation were conducted almost exclusively by Forest Service scientists. By 1963, researchers from both the Forest Service and other institutions and organizations began to realize that Hubbard Brook watersheds could also be used to study nutrient cycles. The HBES developed as a result of these early interests in the combination of hydrologic and nutrient cycles. Today, more than 100 scientists, graduate and undergraduate students work at Hubbard Brook or with Hubbard Brook data, and over 15 principal institutions are associated with the Study. An HBES cooperators' meeting is held annually with over 100 attendees.

Long-Term Ecological Research


Throughfall collector at hardwood site on Watershed 6.

The Hubbard Brook Experimental Forest was designated a Long-Term Ecological Research (LTER) site in 1987 by the National Science Foundation. This additional funding enables scientists at Hubbard Brook to expand their research to evaluate the long-term changes in biogeochemical inputs and outputs to the ecosystem, and to further study the long-term effects of natural and anthropogenic disturbances in the ecosystem. LTER research helps to provide scientifically based information to forest managers.

Biosphere Reserve

Hubbard Brook was designated as a Biosphere Reserve in the Man and the Biosphere Program of the United Nations Educational, Scientific, and Cultural Organization (UNESCO) in October 1976. There are 293 such reserves in 74 countries with 47 of them in the United States. Biosphere Reserves are designed for studying management of land and water resources to meet human needs while conserving natural processes and biological diversity.

National Atmospheric Deposition Program (NADP)

NADP was established to determine the extent and temporal trends of acid precipitation in the U.S. It is a wet (and in some cases dry) deposition monitoring program with 200

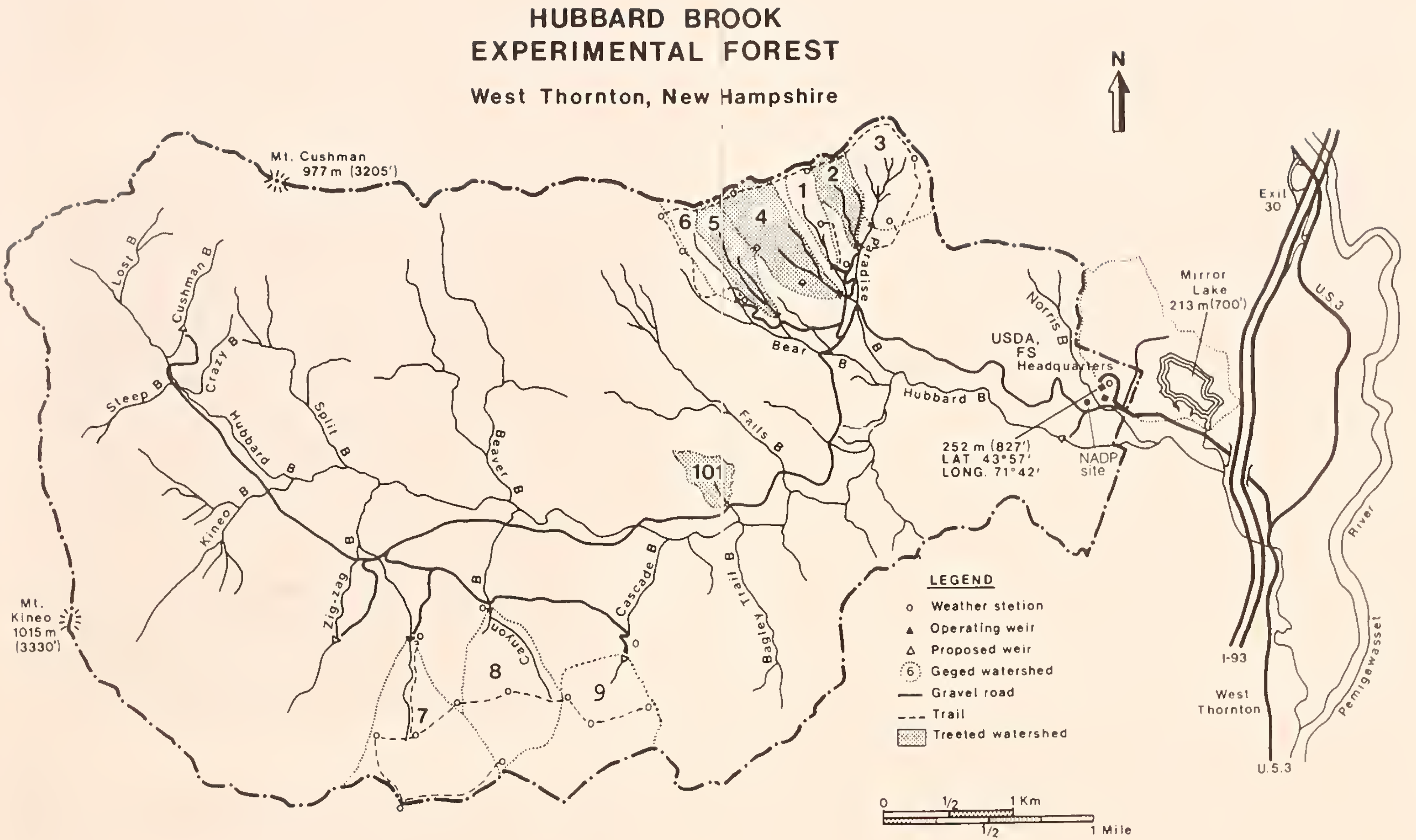
stations nationwide. In order to insure data quality, all sites operate under the same protocol, use the same equipment, and all the samples are analyzed in a central laboratory.

Hubbard Brook, the only NADP site in New Hampshire, has been in the program since its inception in 1978. The average pH of wet precipitation is 4.3 at Hubbard Brook and has remained relatively constant over the study period. Hydrogen, the major cation accounts for 70 percent of all cationic charge, while sulfate accounts for 80 percent of all anionic charge. Sulfate and base cations have shown a slight decline over the past 15 years. National network data demonstrate that acid deposition is highest in the northeastern U.S.

National Atmospheric Deposition Program (NADP) collector and recording rain gage.

Clean Air Status and Trends Network (CASNET)

Since 1988, HBEF has been a routine and special study site for the U.S. EPA's CASNET Dry Deposition Program. There are currently 60 sites in the network collecting chemical and meteorlogical data used to determine the current status and trends in air quality and dry deposition across the United States. Data from the two stations operated at Hubbard Brook are used to assess the effects of terrain on deposition estimates.



HUBBARD BROOK
EXPERIMENTAL FOREST
West Thornton, New Hampshire
N
Mt. Cushman
977 m (3205')
Mt. Kineo
1015 m
(3330')
Lost B
Cushman B
Sleep B
Crazy B
Hubbard B
Split B
Beaver B
Kineo B
Zig-zag B
Canyon B
Cascade B
Bagley Trail B
Falls B
Bear B
Paradise B
Norris B
Hubbard B
USDA, FS Headquarters
Mirror Lake
213 m (700')
252 m (827')
LAT 43°57'
LONG. 71°42'
NADP site
Exit 30
US 3
I-93
West Thornton
U.S.3
Pemigewasset River
1
2
3
4
5
6
7
8
9
101
LEGEND
Weather station
Operating weir
Proposed weir
Gaged watershed
Gravel road
Trail
Treated watershed
0
1/2
1 Km
1/2
1 Mile

Precipitation and Streamwater Chemistry

The longest continuous record of precipitation chemistry in North America is maintained at HBEF, the site where acid precipitation was first documented in North America in 1963. The long-term average is pH 4.2, but has varied considerably between 1963 and 1997 (fig. 3). Decreasing annual concentrations of sulfate, calcium and magnesium were observed during this period, whereas nitrate increased. The origins and complex chemistry of these changes are being investigated. Known effects of atmospheric deposition on forests, streams, and lakes may range from beneficial (fertilization from nitrogen and sulfur) to adverse (toxicity from aluminum or lead).

Stream sampling of the gaged watersheds has accompanied precipitation studies since 1963. Over the length of the record, base cation and sulfate concentrations have declined by 50 percent, and changes in pH have been negligible. The streams are acidic, dilute and normally saturated with dissolved oxygen. The acid neutralizing capacity (ANC) is low.

Mirror Lake

Mirror Lake lies within the Hubbard Brook valley, outside the HBEF boundary, but has been an integral part of the HBES since the 1960s. The lake has a surface area of 15 ha, with a watershed of 85 ha, and a maximum depth of 11 m.

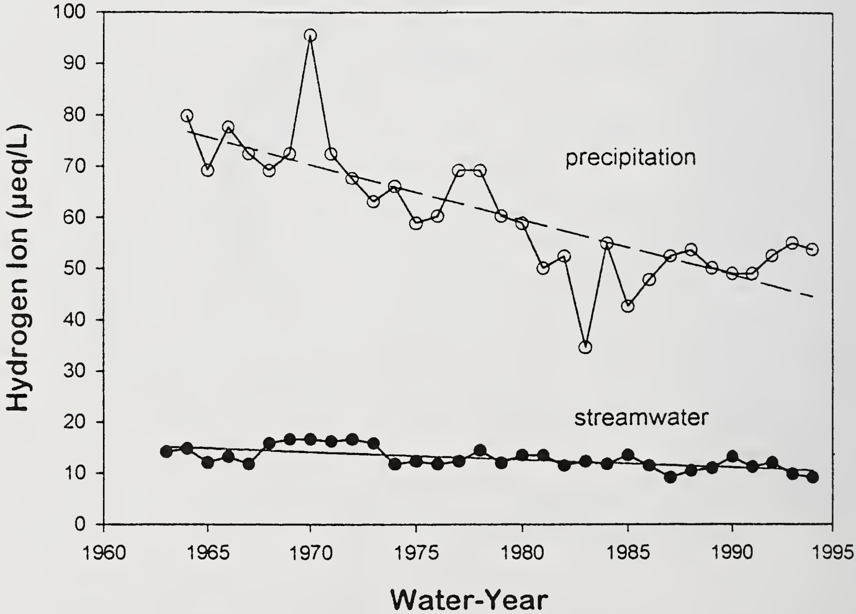


Figure 3.--Annually volume-weighted concentration (µeq/l) of H+ ion for precipitation and streamflow for Watershed 6.

The pH ranges from 6.3 to 6.8 with an acid neutralizing capacity from 75 to 100 meq/L. Surface water temperatures approach 25° C mid-summer. It is relatively nutrient poor and exhibits biannual stratification. Ice-in occurs in early December; ice-out around mid-April.

The watershed has been delineated into three subcatchments, each with a year-round stream gaging station. The outlet, which also has a permanent gaging station, drains into Hubbard Brook. To provide data for an estimate of groundwater flow into or out of the lake, more than 75 research wells have been installed within Mirror Lake watershed. A meteorologic instrument raft, used to calculate lakewater evaporation, is anchored in the lake center during the ice-free season.

Cone Pond

Studies at the Cone Pond Watershed, located 8 km east of the HBEF were initiated in 1980. Although similar to the Hubbard Brook watersheds in many respects, this site provides insights into ecosystem processes not available at Hubbard Brook. Unique features of the 60 ha watershed include a lack of direct human disturbance (no history of human habitation or forest harvest), a dominance of conifer species, several forested wetlands, and a 3 ha, 8 m deep pond. Cone Pond is one of the most acidic ponds in New Hampshire (mean pH 4.6) and provides the ability to evaluate how changes in the atmospheric environment affect sensitive aquatic systems. Although the geologic substrate is superficially similar to Hubbard Brook, this watershed is extremely base-poor compared to Hubbard Brook watersheds. Ongoing studies seek to describe how subtle differences in geology, hydrology and disturbance history might affect base cation nutrition, surface water chemistry, and susceptibility to acidification. Instrumentation includes a cascading series of five stream gages, two rain gages, a weather station, soil moisture/temperature monitors, soil water lysimeters and groundwater well nests in wetlands.

Brook90

Brook90 is a hydrologic computer model which simulates evaporation, snow cover, soil water movement and streamflow. This model was developed at Hubbard Brook based on an earlier widely-used version called Brook2. Brook90 includes water movement through several layers in the soil, and evapotranspiration driven by the Shuttleworth-Wallace method for separating soil evaporation from transpiration in low-density canopies. Vegetation cover is described by leaf area, height, and density; soils are described by texture and rooting depth. The model is designed for any land surface and is expected to be used by engineers, forest managers, scientists and students. Components and simplifications of Brook90 have been included in other models of potential responses to global climate change.

EXPERIMENTAL WATERSHED TREATMENTS

Four cutting operations have been carried out on Hubbard Brook watersheds providing opportunity for researchers to examine various aspects of ecosystem recovery from disturbance. Ongoing studies include investigations of vegetation, hydrology, biogeochemistry, soils and birds. A brief description of each watershed treatment follows:

Watershed 2 (16 ha): In December 1965, all the trees and shrubs on Watershed 2 were felled, lopped to the ground, and left in place. Then the watershed was sprayed with herbicides during the growing seasons of '66, '67 and '68 to greatly reduce transpiration. The objective was to dramatically alter the watershed to study human impacts on forests. The treatment accelerated snowmelt, and increased streamflow (by 30 percent) and growing season NO_3^- concentrations in streamwater (from <1 mg/L to >80 mg/L). Changes in water yield and stream chemistry have been followed for over 30 years (fig. 4).

Watershed 101 (12 ha): In November 1970, Watershed 101 was commercially logged as a stem-only, block, clearcut. Branches and tops were left on site. Watershed 101 has no streamgage, so streamflow was estimated using the hydrologic model Brook2. Simulated streamflow increased 36 percent the first year after cutting and declined steadily until it returned to precutting levels by year 6. Streamwater nutrient loss increased after cutting before returning to precutting levels by year three.

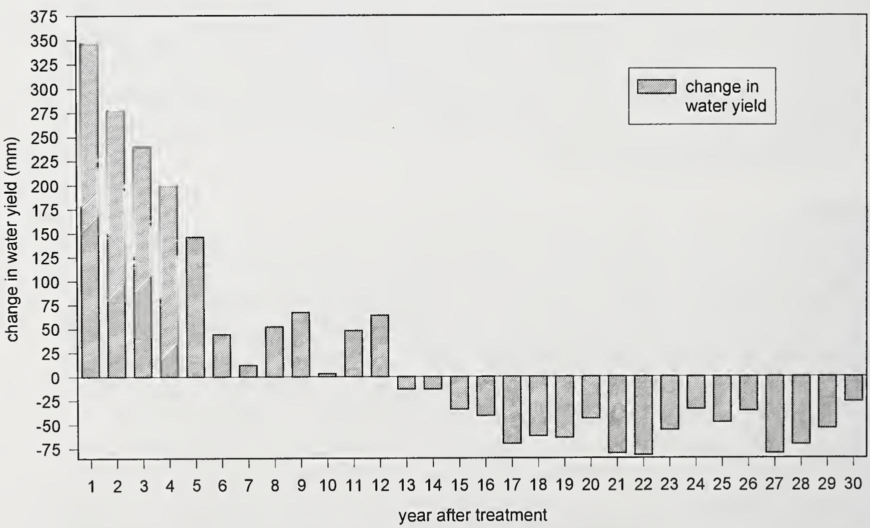


Figure 4.--Change in water yield (mm) for Watershed 2 after treatment.

Watershed 4 (36 ha): During the autumns of '70, '72 and '74, progressive 25 m wide strips, roughly parallel to watershed contours, were cut and merchantable materials removed. Strip cutting did not result in significant increases in erosion. Streamwater nutrient concentrations and water yield increased during and immediately after strip cutting, but in very modest amounts. At year 10, the strip cut had a more desirable mix of commercial species than the block cut on watershed 101, with higher densities of yellow birch and sugar maple and lower densities of pin cherry. In 1992, the vegetation on all strips was inventoried resulting in average biomass of 88 t/ha.

Watershed 5 (22 ha): During the dormant season of '83-'84 a whole-tree harvest occurred on Watershed 5. One hundred and eighty t/ha of biomass were removed. Prior to treatment, the watershed was surveyed into 360 25x25 m plots to be used for research. Clearcutting northern hardwood stands like Watershed 5 result in the following major findings:

- An increase in temperature (as much as 6° C) at the soil surface and in streams, unless streamside buffers of trees are left.
- An increase in moisture content of the soil.

Aerial view of Watershed 5 whole-tree harvested during the dormant season of 1983, 1984.

- A maximum increase in streamflow of approximately 40 percent, and an increase in summer peak flows averaging 20 percent.

- An advance in snowmelt runoff.

- An increase of nutrients, especially nitrate, in the soil solution subject to leaching loss or uptake by plants and micro-organisms.

Feller buncher used in whole-tree clearcutting of Watershed 5.

- No appreciable increase in erosion and sedimentation.

- A decrease by half of the mass of organic matter in the forest floor after cutting.

- Rapid decomposition and fragmentation of slash (75 to 80 percent breakdown in the first 14 years).

- An increase in nitrification.

- Rapid growth of pin cherry and raspberry from seeds which had remained viable in the soil for decades; these pioneer plants conserve nutrients that otherwise might be leached from the site.

TECHNOLOGY TRANSFER

Hubbard Brook Tours

Over 700 college students, visiting scholars, school teachers and interested citizens visit Hubbard Brook annually. Introductory slide shows and guided tours into the research forest are offered upon prior arrangement.

Data Access

Some of the many users of Hubbard Brook data include the Green and White Mountain National Forests, forest industries, The National Academy of Sciences, state and federal agencies, and students. Public access to data collected by the HBEF and the HBES is encouraged and is available electronically at the Hubbard Brook web site. For further information, contact the Hubbard Brook Data Manager at the Forestry Sciences Laboratory, P.O. Box 640, Durham, NH 03824.

Publications

Hubbard Brook data has been the subject of more than 1,200 publications since the start of the project in 1955. A yearly updated list of these publications contributed by Hubbard Brook researchers is available in the "Publications of the Hubbard Brook Ecosystem Study" or electronically at the Hubbard Brook web sites.

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